PHYSICAL GEOGRAPHY OF NEW YORK STATE.

BY

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PART VIII.—THE GREAT LAKES AND NIAGARA.

POST-GLACIAL HISTORY.—Indian trails in New York were located upon a gravel ridge, which later became the site of a road, known as the ridge road. This gravel ridge was early recognized as a lake beach. For instance, Governor Clinton* says that a lake evidently once covered this region, its level having been lowered either by an earthquake shock or by the enlargement of the outlet. Atwater† states that Lake Erie was once higher, covering the prairies of the Ohio region, and flowing into the Ohio, the level of this lake having been lowered by the cutting of the Niagara gorge. Bigsby‡ points out that elevated beaches prove that there have been fluctuations in the level of Lake Huron, and he also mentions the elevated beaches near the shores of Lake Ontario,§ as does Captain Basil Hall,‖ who recognized that Lake Ontario once stood higher.

Whittlesey** advocated beach origin for the ridges in Ohio, but pointed out the difficulty of explaining them, because of the absence of natural barriers. Later†† he studied these beaches more extensively; and, after proving that they were not strictly level, concluded that they therefore were not beaches, but probably due to marine currents, being in the nature of bars. The same author later studied the beaches of the Michigan region,‖‖ and stated that the lower ones were lake beaches, exposed to the air by a lowering of the outlet, but that the upper ones were more ancient, and due to a more perma-

* Coll. of the Hist. Soc. of N. Y., 1811, Vol. II, 94–96.

† Amer. Journ. Sci., 1819, I, 116–125. This is opposed by Wells, Same, 331–337, and by Bourne, Same, 1820, II, 30–34.

‡ Trans. Geol. Soc., 1824, I, 2nd Ser., 175–208.

§ Phil. Mag., 1829, V, 2nd Ser., 6.

‖ Travels in North America, Edinburgh, 1829, Vol. I, 167–170.

** Second Ann. Rept. Geol. Survey of Ohio (Mather), 1838, 55.

†† Outline Sketch of Ohio, 1848 (from Homer Historical Collections), 586–589; Amer. Journ. Sci., 1848, LV, 205–217; Same, 1850, LX, 31–39.

‖‖ Foster & Whitney's Lake Superior Rept., Part 2, 1851, 270–273; See also Whittlesey, Smithsonian Contributions to Knowledge, 1867, XV, Article II, 17–22.

nent elevation of the water. These studies of Whittlesey's were the earliest ones of marked importance, and it will be noticed that he recognizes some important features, such as the fact that the beaches are not level. Roy* found and described the beach terraces of Canada and ascribed them to inland lakes whose barriers had disappeared.

In New York, Hall† described the lake beaches and the ridge road, which he recognized as a true beach. The Erie terraces were also mentioned; and the terraced deltas of the Cayuga and Seneca valleys were explained as the result of former water levels, though he was doubtful as to the exact conditions then existing. Hayes‡ ascribes the beaches to ocean action, and Niagara gorge to the work of high and powerful tides. Lyell,§ who visited the terraces in both New York and Canada, in the latter country in company with Roy, and in the former with Hall, notes their remarkable general levelness, and asks how the barriers supposed by Roy could have been removed without disturbing this levelness. To account for them he supposes that they are marine, and that the land has been elevated vertically above the sea. Some terraces are believed to be beaches, some bars; and this difference in origin, together with variations in supply, and in original surface contour, *plus* a slight difference in amount of uplift, he believes will account for the measure of irregularity noticed.

Lapham‖ describes the lake clays near Lake Michigan; and Agassiz** proposes to account for the terraces which line the shores of Lake Superior by a change in the relative elevation of the lake and its shore, the change being in the land itself, not in the water. These changes were in the nature of paroxysms, causing frequent changes, and the cause for these paroxysms is believed to be the intrusion of dikes, of which large numbers occur on the shores of Superior.

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* Phil. Mag., 1837, XI, 201–202.

† Second Rept. Geol. New York, 1838, 310–314; 348–350; Geol. of New York, 4th Dist., 1843, 342–354; 661–662.

‡ Amer. Journ. Sci., XXXV, 1839, 95–105.

§ Phil. Mag., 1842, XXI, 548–555; Proc. Geol. Soc., III, 595; Phil. Mag., 1843, XXIII, 183–186; Amer. Journ. Sci., 1844, XLVI, 314–317; Travels in North America, Vol. I, 1845, 24; Vol. II, 85; 102–114. Considerable important work done in Canada by Roy, Fleming and others, and published upon in the Canadian Journal, Canadian Naturalist, and other Canadian publications, has not been examined, because I have not had access to sets of these journals.

‖ Amer. Journ. Sci., 2nd Ser., III, 1847, 90, 94.

** Proc. Amer. Assoc. Adv. Sci., 1849, I, 68–70; Lake Superior, Boston, 1850, 413–416; Amer. Journ. Sci., 2nd Ser., 1850, X, 98–101.

Desor* advocates marine origin for the beaches of Superior and Ontario, pointing out that they need not stand at the same level, some being formed in more exposed places than others, and some, after having been formed, being destroyed, while others are really submarine terraces (œsars). The marine origin is indicated by the distinctly marine terraces of the St. Lawrence Valley, in which marine fossils occur; and the changes in conditions have come as a result of the uplift of the land. On the other hand Chapman,† agreeing with Roy, advocates fresh water origin and assumes that this fresh water was held in lakes raised in level by some eastern barrier.

With the studies of the Ohio Geological Survey there began a more scientific investigation of the shore lines, and Newberry,‡ as a result of his studies, attributed the beaches to a vast inland sea, which gradually contracted, for some unknown reason, possibly local subsidence, or erosion along channels of drainage. He suggests that the exact cause will be known only after careful future study, which calls for a detailed tracing of the several ridges. He gives one of the first clear arguments for the lacustrine origin of the lake ridges as opposed to the marine.

Bannister,§ describing the beaches of Lake Michigan near Chicago, refers them to a former level of Lake Michigan and describes the outflow past Chicago, which is still recognized as a former outlet. This is one of the best early pieces of work upon the lake shores. Warren,‖ on the other hand, ascribes the beaches of the Red River valley, and some of the changes in the Great Lakes, to a change of land level.

It was as an assistant to Newberry that Gilbert** began his work upon the Great Lakes, a work which has produced such important results. He gave us the first detailed survey of a kind sufficiently accurate to be used in later mapping (Fig. 1). In connection with

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* Foster & Whitney's Lake Superior Rept., Part I, 1850, 194–218; Same, Part II, 1851, 232–270; Bull. Geol. Soc. France, 1850, VII, 623–630; Bull. Geol. Soc. France, 1851, VIII, 420–423.

† Phil. Mag., XXI, 1861, 428–435.

‡ Proc. Boston Soc. Nat. Hist., 1862–3, IX, 42–46; Geol. Survey, Ohio, 1869 Report, 24–31; Ann. New York Lyceum Nat. Hist., 1870, IX, 213–34; Amer. Nat., 1870, IV, 193–214.

§ Illinois Geol. Survey, 1868, III, 240–242.

‖ Ann. Rept. Chief of Engineers, 1868, 307; Amer. Journ. Sci., 1878, CXVI, 416–431.

** Geol. Survey, Ohio, 1870, I, 488–495.

his work on the Maumee Valley,* Gilbert showed that the beaches must have been formed in lakes, because they converged toward the outlet channel past Fort Wayne, and that they have been tilted since formation. This tilting has later been used as proof that the change in land level was the cause for the change in outflow of the lakes and hence in the former lake levels. He also points out that, since they dropped from the level of the highest beaches, the waters of Lake Ontario have been at least seventy feet lower than now. This paper of Gilbert's marks a very distinct advance in our knowledge of the Great Lakes history.

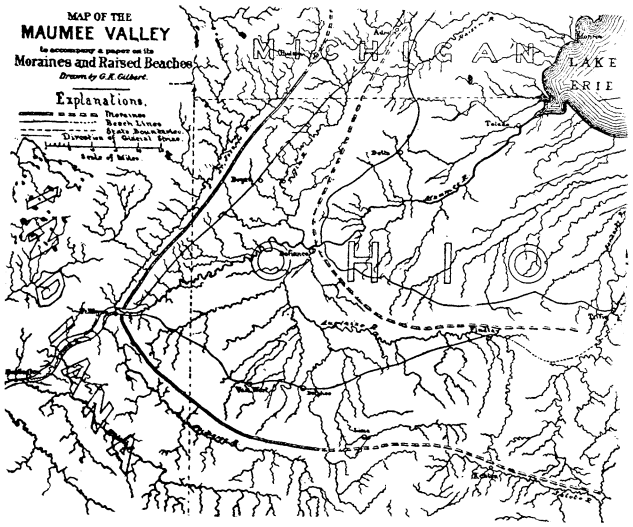

FIG. 1.—THE MORAINES AND BEACHES OF THE MAUMEE VALLEY (GILBERT).

Another assistant to Newberry, Professor Winchell, was also engaged in the study of some of the Ohio terraces, some of the lower ones of which he referred to beach origin, others to glacial moraines, modified by water. The elevation of the lake waters is ascribed to the freezing up of all the outlets. Winchell inaugurated the policy of giving names to the various lake ridges.† The ridges were still further studied and described by Orton‡ and by Read§ of the Ohio Survey.

* Proc. New York Lyceum Nat Hist., 1871, I, 175–178; Amer. Journ. Sci., 1871, CI, 339–345; Geol. Survey, Ohio, 1873, Vol. I, 537–56.

† Winchell, Proc. Amer. Assoc. Adv. Sci., 1872, XXI, 152–186; Geol. of Ohio, 1874, II, 56; 431–433.

‡ Geol. Survey of Ohio, 1873, I, 425–434; 438–449; 455–462.

§ Geol. Survey of Ohio, 1873, I, 488–492; 516–519.

In a foot-note to Gilbert's paper, Newberry* makes the suggestion which Gilbert and most other workers have since accepted. He says, "In the discussion of these facts cited by Mr. Gilbert, and others of similar character, it should be remembered that the retreating glacier must have, for ages, constituted an ice dam that obstructed the natural lines of drainage, and may have maintained a high surface level in the water-basin which succeeded it." Since then† this theory has been more fully stated; and Newberry, Gilbert and others, have accepted it, first as a working hypothesis and later as a well-established explanation.

By the subsequent work of a number of writers a very large body of fact has been obtained. Chamberlin,‡ describing the beaches of Lake Michigan, states that they are due to fresh water lakes, caused by land movement, the proof of this being the lack of uniformity in the level of the beach ridges.

Claypole§ accepts the ice dam theory and states his views concerning the mode of retreat of the ice cap and the resulting lakes. Dryer‖ describes in detail some of the beaches in Indiana, and Lawson** makes a very complete statement concerning the beaches along the northern shore of Lake Superior. He questions the glacial dam theory and calls for warping to account for the changes in outlet which have caused variations in level.

Spencer, one of the pioneers in the study of the Great Lakes, has gathered a large body of fact and added a great deal to our knowledge concerning the Great Lakes.†† He ascribes the former

* Geol. Survey of Ohio, 1873, I, 552.

† Geol. Survey of Ohio, II, 1874, 21–65; 72–80; Proc. New York Lyceum Nat. Hist., II, 1874, 136–138; Geol. Survey of Ohio, 1873, III, 32–51; Proc. N. Phil. Soc., 1882–3, XX, 91–95.

‡ Geol. Survey of Wisconsin, 1877, II, 219–233.

§ The Lake Age in Ohio (from Trans. Geol. Soc., Edinburgh), 1887. Edinburgh, 42 pp.

‖ Indiana Geol. Survey, 16th Rept., 1889, 98–126; Same, 17th Rept., 1892, 114–134; 160–170; Same, 18th Rept., 1894, 17–32; 72–90. Studies in Indiana Geography, Terre Haute, 1897, 42–52.

** Twentieth Rept. Minnesota Geol. Survey, 1891, 181–289.

†† See Spencer, Proc. Amer. Phil. Soc., 1880–81, XIX, 300–337; Same, 2nd Geol. Survey Pennsylvania, Rept. QQQQ, 1881, 357–406; Proc. Amer. Assoc. Adv. Sci., 1881, XXX, 131–146; Proc. Amer. Assoc. Adv. Sci., 1882, XXXI, 359–363; Amer. Journ. Sci., 1882, CXXIV, 409–416; Geol. Mag., 1887, IV, 167–173; Amer. Nat., 1887, XXI, 168–171; Proc. Amer. Assoc. Adv. Sci., 1888, XXXVII, 197–199; Science, 1888, XI, 49; Bull. Geol. Soc. Amer., 1889, I, 65–70; Trans. Roy. Soc. Canada, 1889, VII, Sect. IV, 121–134; Bull. Geol. Soc. Amer., 1889, I, 71–86; Quart. Journ. Geol. Soc., XLVI, 1890, 523–533; Amer. Journ. Sci., 1890, CXL, 443–451; Amer. Geol., 1890, VI, 294; Amer. Journ. Sci., 1891, CXLI, 12–21; Amer. Geol., 1891, VII, 86–

high-water level to marine action, though in this view he now stands practically alone. Not only does he refer to this origin the beaches recognized distinctly by others, but high deposits of stratified drift are assigned by him to the same cause, which would imply a very extensive submergence of the land, and this is Spencer's belief. He himself, together with other workers, has shown that there has been extensive warping,* which has finally dismembered the great water bodies and formed the present Great Lakes. Many of the lake stages which Spencer has worked out, and to which he has given names, are now recognized, though in some cases the construction placed upon facts by others is different from his.

Taylor has made careful studies in the region around the shores of the various lakes, and has given us a body of fact of great importance.† From his studies he was at first led to explain the beaches as the result of marine submergence, which extended over the entire Great Lakes region into the Red River valley, and northward to Hudson Bay (Fig. 2). The upper, earlier beaches, connected with overflow channels, were thought to have been caused by glacial dams; but the strongly developed beaches lower than these, were believed to have resulted from marine submergence, while certain recent

97; Amer. Geol., 1891, VII, 266; Amer. Journ. Sci., 1891, CXLI, 201–211; Bull. Geol. Soc. Amer., 1891, II, 465–476; Geol. Mag., 1891, VIII, 262–272; Bull. Geol. Soc. Amer., 1892, III, 488–491; 491–492; 494–495; Amer. Geol., XV, 1894, 135–136; Proc. Amer. Assoc. Adv. Sci., 1894, XLIII, 237–243; Amer. Geol., 1894, XIV, 289–301; Proc. Amer. Assoc. Adv. Sci., 1894, XLIII, 244–246; Amer. Journ. Sci., 1894, CXLVIII, 455–472; Amer. Nat., 1894, XXVIII, 859; Amer. Journ. Sci., 1894, CXLVII, 207–212; Proc. Roy. Soc., 1894, LVI, 145–148; Eleventh Rept. Niagara Comm., 1895, Appendix, 126 pp. (Reprint of a number of papers); Popular Sci. Mon., 1896, XLIX, 157–172; Proc. Amer. Assoc. Adv. Sci., 1896, XLIV, 139; Amer. Geol., 1898, XXI, 110–123. Because of the brief space available, it is impossible to state Spencer's views more fully and to refer more specifically to each of his contributions.

* As has been pointed out before, this warping was early recognized; but for an excellent general statement of this subject see de Geer, Proc. Boston Soc. Nat. Hist., 1892, XXV, 454–477; Amer. Geol., 1893, XI, 22–44.

† Amer. Journ. Sci., 1892, CXLIII, 210–218; Bull. Geol. Soc. Amer., V, 1894, 620–626; Amer. Geol., 1894, XIII, 316–327; Same, XIII, 365–383; Same, XIV, 273–289; Amer. Journ. Sci., 1895, CXLIX, 69–71; Amer. Geol., 1895, XV, 24; Amer. Journ. Sci., 1895, CXLIX, 249–270; Amer. Geol., 1895, XV, 100–120; 162–179; 394; Same, 304–314; Amer. Geol., XVII, 1896, 253–257; Same, 1896, XVII, 397–400; Inland Educator, 1896, II; Studies in Indiana Geography (Dryer), Terre Haute, Ind., 1897, 90–110; Amer. Geol., 1896, XVIII, 108–120; Bull. Geol. Soc. Amer., 1897, VIII, 31–58; Amer. Journ. Sci., 1897, CLIII, 208; Amer. Geol., 1897, XIX, 392–396; Amer. Geol., 1897, XX, 65–66; 111–128; Proc. Amer. Assoc. Adv. Sci, 1897, XLVI, 201–202; Bull. Geol. Soc. Amer., 1898, IX, 59–84.

changes were ascribed to tilting of the land, of which he states proof. In 1896, however, Taylor * announces his conversion to the glacial-dam theory, thus removing one of the two chief supporters of the hypothesis of marine origin.

Upham has added many facts to our knowledge of the postglacial history of the Great Lakes.† He has vigorously upheld the ice-

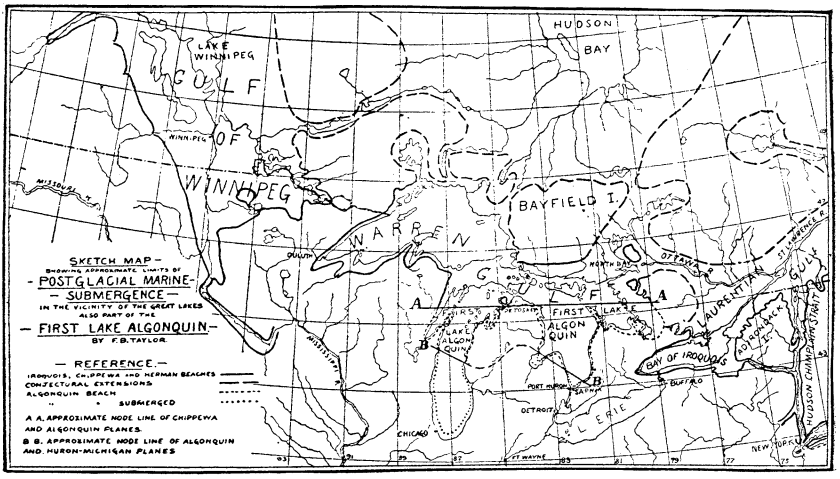

FIG. 2.—TAYLOR'S MAP SHOWING THE CONCEPTION THAT HE AT FIRST HAD CONCERNING THE SUPPOSED MARINE ORIGIN OF THE BEACHES OF THE GREAT LAKES' REGION.

dam theory, and has described the outlet of the higher Lake Superior waters, as well as the beaches around the shores of Lake Superior and elsewhere. He has also stated fully his interpretation of the succession of events connected with the withdrawal of the ice sheet from the Great Lakes' basins. Upham has also given us that classic monograph upon glacial Lake Agassiz, the most remarkable of the ice-dammed lakes.‡

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* Amer. Geol., 1896, XVII, 253–257.

† Proc. Amer. Assoc. Adv. Sci., 1883, XXXII, 230; Final Rept., Minnesota Geol. Survey, 1888, II, 642–643; Bull. Geol. Soc. Amer., 1890, I, 563–567; Same, 1891, II, 258–265; Same, III, 1892, 484–487; Twenty-second Rept., Minnesota Geol. Survey, 1894, 54–66; Nature, 1894, L, 198–199; Amer. Geol., 1894, XIV, 62–65; Proc. Rochester Acad. Sci., 1895, II, 196–198; Twenty-third Rept. Minnesota Geol. Survey, 1895, 156–193; Bull. Geol. Soc. Amer., 1895, VI, 21–27; Amer. Journ. Sci., 1895, CXLIX, 1–18; Amer. Geol., 1895, XV, 396–399; Bull. Geol. Soc. Amer., 1896, VII, 327–348; Amer. Geol., 1896, XVII, 238–241; Amer. Geol., 1896, XVIII, 169–177; Monog. XXV, U. S. Geol. Survey, 1896, 255–264; Bull. Geol. Soc. Amer., 1898, IX, 101–110.

‡ Monog. XXV, U. S. Geol. Survey, 1896. In this, references to his previous articles on Glacial Lake Agassiz can be found.

Gilbert, who gave us the first full study of a portion of the Great Lakes' beaches, has by later study contributed a great deal

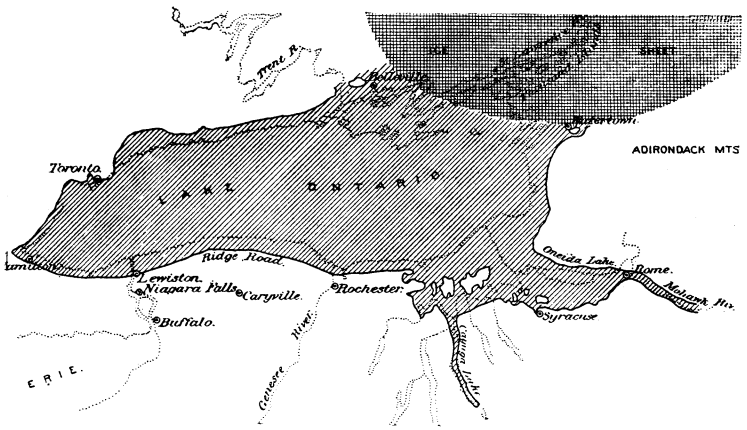

FIG. 3.—GILBERT'S MAP OF GLACIAL LAKE IROQUOIS.

to our knowledge of the eastern lakes.* He has traced the Ontario shore line in New York (Fig. 3), and pointed out its relation to the

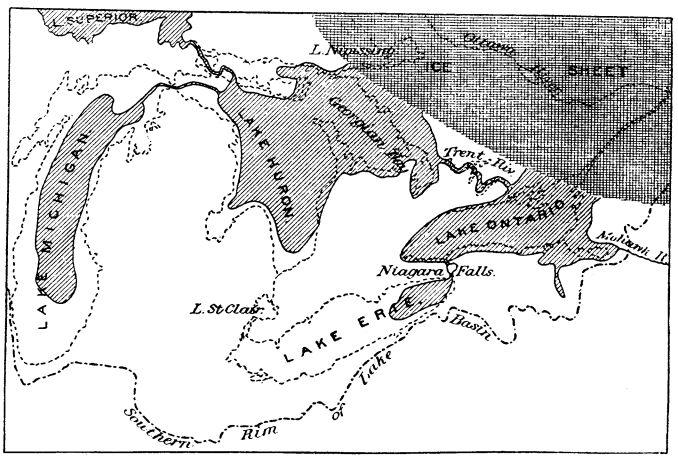

FIG. 4.—GILBERT'S MAP OF THE GREAT LAKES DURING THE TIME WHEN THE ST. LAWRENCE WAS ICE-BLOCKED.

Mohawk outflow: he has proved that the land has been tilted since the beaches were formed, and that it is probably even now

* See Science, 1885, VI, 222; Proc. Amer. Assoc. Adv. Sci., 1886, XXXV, 222–3; Science, 1886, VIII, 205; Forum, 1888, V, 417–428; Sixth Rept. Niagara Comm., 1890, 61–84; Smithsonian Rept. 1890, 231–257; Internat. Congress Geologists, 5th Session, (1891), Washington, 1893, 455–458; Bull. Geol. Soc. Amer., 1892, III, 492–493; Same, 493–4; Amer. Journ. Sci., 1895, CL. 18; Bull. Geol. Soc. Amer., 1895,

rising. Gilbert has also stated that Ontario was formerly lower than now, and that the volume of Niagara has changed as a result of the variation in outlet of the Great Lakes (Figs. 4 and 5). He has also pointed out that the Ontario shore line disappears on the northern flank of the Adirondacks, as if there had been at that place some dam, like an ice dam, which held up the lake waters (Figs. 3 and 4). He has also proved the existence of former channels in New York, caused when the waters were escaping toward the Mohawk outflow.*

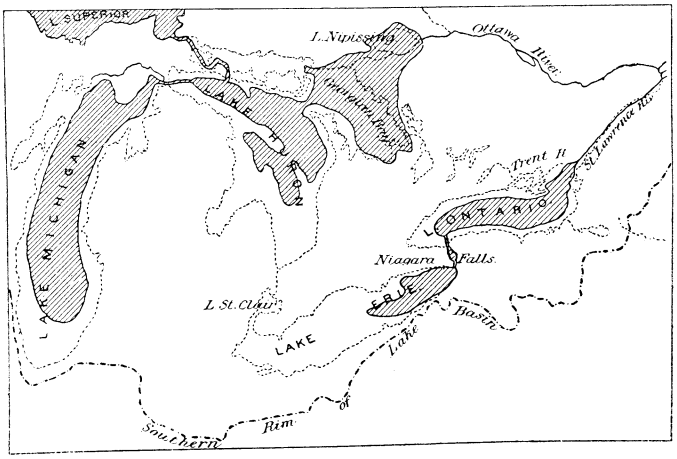

FIG. 5.—GILBERT'S MAP OF GREAT LAKES AFTER THE ICE HAD LEFT THE ST. LAWRENCE AND BEFORE THE UPPER AND LOWER LAKES WERE FINALLY CONNECTED.

Leverett† has done much painstaking work on the shore lines, especially of Erie and Michigan, and has added a great deal to the glacial dam theory by pointing out the relation between the frayed-out ends of beaches and glacial moraines. During his studies in Ohio, Gilbert had noted the disappearance of the Erie beaches toward the east, and he later proved the same thing for the Ontario shore in the Adirondack region. Suggesting to Leverett the probability of the discovery of moraines where these beaches disap-

VI, 466; Amer. Geol., 1896, XVIII, 231; Physiography of the United States, 1896, 203–236; Bull. Geol. Soc. Amer., 1897, VIII, 285–286; Nat. Geog. Mag., 1897, VIII, 233–247; Eighteenth Annual Report U. S. Geol. Survey, 1898, 595–647.

* Bull. Geol. Soc. Amer., VIII, 1897, 285–286; See also Quereau, Same, IX, 1898, 173–182 and Davis, Popular Sci. Mon., 1894, 218–29.

† Trans. Wisconsin Acad. Sci., 1889, VII, 177–192; Same, 1892, VIII, 233–240; Amer. Journ. Sci., 1892, CXLIII, 281–301; Same, 1895, CL, 1–20; Chicago Acad. Sci., (Geol. and Nat. Hist. Survey, Bull. 2) 1897, 55–86; Amer. Geol., 1898, XXI, 195–199.

peared, these were looked for and found by Leverett, and their relation to the beaches stated (Fig. 6).

In New York Fairchild* is at work on the early stages of the glacier-dammed lakes; and by his studies he has proved the existence of numerous small lakes, with southern outlets, before their waters were united to cause the larger glacial lakes described by others.†

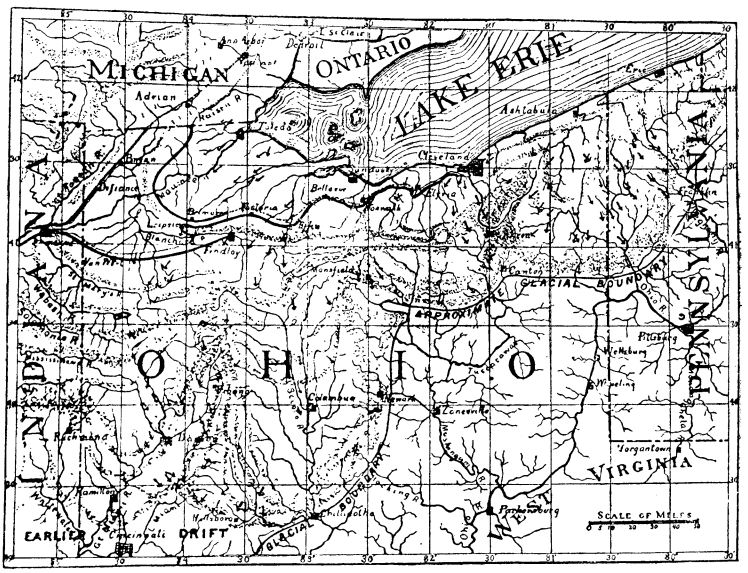

FIG. 6.—LEVERETT'S MAP OF BEACHES AND MORAINES OF OHIO.

CONSIDERATION OF THE THEORIES.—With this brief statement of the progress of ideas, and the references to the writings of the chief workers, I shall now attempt to state what seems to me to be the *most probable* post-glacial history. Here again, as in the first part of the paper, it is to be understood that I make full use of all

* Bull. Geol. Soc. Amer., 1895, VI, 353–374; Same, 462–466; Same, 1896, VII, 423–452; Same, 1897, VIII, 269–284; Same, X, 1899, 27–68.

† For other articles relating to this subject, see Claypole, Amer. Nat., 1886, XX, 856–862. Wright, Proc. Amer. Assoc. Adv. Sci., 1889, XXXVIII, 1889, 247; Bull. Geol. Soc. Amer., 1893, IV, 423–425. Davis, Amer. Geol., 1890, VI, 400; Amer. Geol., 1891, VII, 139; Popular Sci. Mon., 1894, 218–229. Bell, Bull. Geol. Soc. Amer., 1893, IV, 425–427. Hill, Amer. Geol., XIV, 1894, 405. Shaler, Bull. Geol. Soc. Amer., 1895. VI, 151–152. Mudge, Amer. Journ. Sci., 1895, CL, 442–445. Tarr, Bull. 109 Cornell Univ. Agric. Experiment Station, 1896, 90–122. Winchell, Amer. Geol., 1897, XIX, 336–339. Elftman, Amer. Geol., XXI, 1898, 101–109. Brigham, Bull. Geol. Soc. Amer., 1898, IX, 183–210. Russell, Bull. Amer. Geog. Soc., 1898, XXX, 226–254.

the literature referred to, as well as of some studies of my own, and from these draw such conclusions as appear to me to be warranted.

The raising of land barriers to the northeast, which was early suggested, is no longer held; and, if it were, it could be easily disproved, the best proof against it being the absence of beaches where the land barriers would have existed. The present lake ridges gradually disappear toward the east, as if the barrier or dam forming the lakes had also disappeared. The mere lowering of the land barrier would not destroy the beaches that were formed against it.

Concerning the marine hypothesis, the arguments in favor of it, so far as I am able to find, are first, the supposed discovery of evidence of high shore lines, so high that ice dams could not by any possibility explain them. It is to be noted that some of these, as those in the Cayuga and Seneca valleys, are directly connected with overflow channels, as shown by Gilbert, Wright * and Fairchild, while others of the supposed marine deposits are ascribed by most glacialists to glacial origin, and not to marine action. Few geological hypotheses rest upon a more insecure basis than that of deep post-glacial submergence of northeastern America, as upheld by Spencer and others. Until much better evidence of it is brought forward, it need not seriously influence our discussion concerning the history of the Great Lakes.

A second point, proposed by Spencer, † is that an ice dam is incapable of holding back such volumes of water. Such an argument is not very strong, especially if there is good evidence that ice dams *did* hold back water bodies of large size. Most glacialists believe that a great and deep ice sheet, occupying the entire St. Lawrence valley, is a sufficiently strong dam to hold a large lake in check; and this belief is greatly strengthened by the almost certain evidence of the existence of such a dam.

A third point advanced in favor of the marine hypothesis is the fact that there *are* marine beaches in the Hudson, Lake Champlain, Ottawa and St. Lawrence valleys, ‡ in which marine fossils are

* Proc. Amer. Assoc. Adv. Sci., XXXVIII, 1889, 247.

† Geol. Mag., VIII, 1891, 262–272.

‡ See Merrill, Trans. New York Acad. Sci., 1890, IX, 78–83; Amer. Journ. Sci., 1891, CXLI, 460–466. Davis, Proc. Boston Soc. Nat. Hist., 1891, XXV, 318–34. Hitchcock, Geol. of Vermont, Vol. I, 1861, 93–167. Baldwin, Amer. Geol., XIII, 170–184. Logan, Canadian Geol. Survey, 1863, 896–930. Dawson, Amer. Journ. Sci., CVIII, 1874, 143. The Canadian Ice Age, Montreal, 1894 (with references to the literature). Ells, Bull. Geol. Soc. Amer., 1898, IX, 211–222. This is by no means a complete list of references on this subject; but from these, other references may be obtained.

found. Against the correlation of these beaches with those of the Great Lakes may be argued the fact that, although the marine deposits and the lake beaches are both well developed in their respective localities, there has been no direct connection traced between them, although it has been attempted by several. No marine fossils have been discovered in the lake beaches, although such fossils abound in the marine beaches further down the St. Lawrence valley; but this absence of fossils is explained by the advocates of the marine hypothesis on the assumption that this great arm of the sea contained either fresh or brackish water, or else that the marine fossils did not have time enough to enter them from the sea.*

The existence of marine forms at present living in the Great Lakes† is also argued in favor of marine invasion; but if this proves anything, it proves merely that salt water entered the basins at one stage, which may be granted easily, without attempting to explain all the beaches by marine action. Moreover, if this marine fauna of the lakes is due to an incursion of the sea while the beaches were forming, it is rather remarkable that no remains of such a fauna have been discovered in the present beaches.‡

There seems very little in favor of the marine hypothesis, and there are numerous facts against it, and in favor of ice dams, which have never yet been satisfactorily answered. One of the strongest objections to the marine hypothesis is that the beaches end toward the east, as if the waves had worked there against some dam, like ice, which could not record their work after the ice had gone. It is true that Spencer claims that the beaches *do not* end as reported,§ and that the moraine accumulations near their ends *are not* in reality connected with them. It is too soon to pronounce a final opinion upon this latter disputed point, for naturally the ends of beaches in an ice-dammed lake will not be abrupt, but gradual, and difficult to locate definitely; and, moreover, moraines built during the recession of an ice sheet,

* Spencer, Proc. Amer. Assoc. Adv. Sci., 1882, XXXI, 359–363; Geol. Mag., VIII, 1891, 262–272; Amer. Geol., 1894, XV, 135–136.

† Hitchcock, Proc. Amer. Assoc. Adv. Sci., 1870, XIX, 175–181. Stimpson, Amer. Nat., 1870, IV, 403. Smith, Ann. Rept. U. S. Fish Comm., 1872–3, 643–644. Nicholson Ann. and Mag. Nat. Hist., Ser. IV, 1872, X, 276–285; Chamberlin in Geikie's Great Ice Age, 3d Ed. 1894, p. 769.

‡ Since this article was printed, there has appeared an important paper by Coleman (Bull. Geol. Soc. Amer., X, 1899, 165–176), in which it is announced that *fresh water* fossils have been discovered in the elevated beaches at Toronto.

§ Amer. Geol., 1890, VI, 294; Bull. Geol. Soc. Amer., 1892, III, 488–491, 494; Amer. Geol., 1898, XXI, 110–123. See Leverett's reply to last in Amer. Geol., 1898, XXI, 195–199.

while the front stood in a lake, might well fail to be formed, or else might have been formed with a very indefinite development.

With reference to the first point, it is noteworthy that in one case where Spencer has claimed to have continued the beaches beyond the supposed end, both Gilbert and Taylor,* working in the field in company with Spencer, have not been able to recognize his beaches, although pointed out by their discoverer. Gilbert and Taylor explain by other causes than wave action the deposits assumed to be beaches by Spencer. It seems fair, therefore, to hold to the belief that the beaches *do* come to an end where claimed, since all the workers in the field, excepting one, have reached this conclusion as the result of their observations; and if this conclusion is correct, then the ice-dam theory is strongly supported. Indeed, the very fact that Spencer himself admits that the connecting beaches, if they really exist, are indistinct, while elsewhere, both on the seaward and landward side, they are strongly developed, argues against the marine hypothesis.

Then, also, the overflow channels furnish an unanswered and apparently unanswerable argument against the hypothesis that the beaches were formed in arms of the sea; for it seems evident that *rivers have flowed out* through these channels from the landward toward the seaward side; and, as Davis states, it is difficult to understand how a river could flow from one arm of the sea to another. The shore lines converge toward these outlets and are strongly developed on the lake side, but have not been shown to exist on the opposite side, and in some cases are *certainly* not present there. Where, then, are the shore lines that would have been formed on the southern side of the St. Lawrence divide if the sea covered that land? Although Spencer has attempted to answer this objection of Davis', his reply does not seem satisfactory.†

Everything indicates that the former high levels of the Great Lakes were due to ice dams, as first suggested by Newberry; and the proof of this theory is so strong that opinion is now all but unanimous in favor of its acceptance. It is nearly established as a fact, though for a while should probably be considered still as a working theory. Accepting this, then, as the probable explanation, I will briefly state the history of change from the first beginning of the

* See Spencer, Bull. Geol. Soc. Amer., 1892, III, 488–491; 494. See also reply by Gilbert, Same, 492–493; also Taylor, Amer. Geol., 1897, XIX, 392–396.

† See Davis, Amer. Geol., 1890, VI, 400; Same, 1891, VII, 139. Spencer, Same, 266; Bull. Geol. Soc. Amer., 1892, III, 491–492; 495. Gilbert, Same, 493–494. Spencer, Proc. Amer. Assoc. Adv. Sci., 1896, XLIV, 139.

withdrawal of the ice sheet to the present condition of the lakes, so far as this history has been worked out, following in this chiefly the interpretations of Gilbert and Taylor.*

THE ICE-DAMMED LAKES.—During its southernmost extension the glacier covered all the basin of the Great Lakes system. As this ice sheet encroached upon the region, it must have formed numerous marginal lakes, though of these no records have yet been discovered. When the ice cap finally began to withdraw, it retreated northward and northeastward, uncovering first of all the southern portions of the drainage area. In these north-flowing stream val-

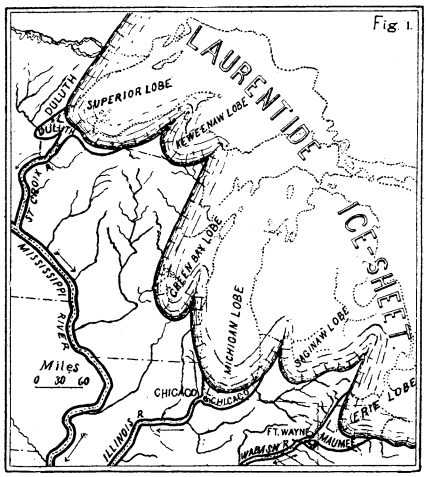

FIG. 7.—TAYLOR'S MAP OF LOCAL ICE MARGIN LAKES.

leys, tiny lakes existed, growing in size as the ice dam took successively more and more northerly positions. The map (Fig. 7) shows the approximate location of three of the largest of these lakes. Within the State of New York such lakes existed at a later time in the Champlain, Genesee, Seneca, Cayuga and other valleys.

As the ice dam melted further back, lower outflows were discovered, and the level of the lake waters fell. At the same time the small marginal lakes successively coalesced and flowed out through one outlet instead of two or more. For instance, note how, as shown in Fgures 7 and 8, the Maumee Lake has expanded to Lake Whittlesey, and, escaping across the lower Michigan peninsula

* Gilbert, Sixth Ann. Rept. Niagara Comm., 1890, 61–84; Physiography of United States, 1896, 203–236; Taylor, Studies in Indiana Geography (Dryer), Terre Haute, 1897, 90–110.

into the enlarged Lake Chicago, finds an outflow into the Illinois River past Chicago.

During the early part of this stage of coalescing marginal lakes, New York was largely under cover of the ice; but in time the same stage visited this State. At first there were numerous tiny lakes, which enlarged and coalesced, abandoning one outlet after another, until the several lakes of the Finger Lake region united into one branching lake, with an outflow over the Seneca Lake divide, forming what Fairchild proposes to call Glacial Lake Newberry. As

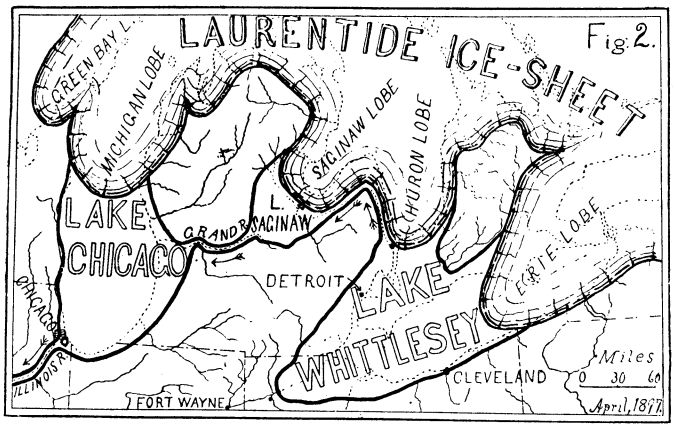

FIG. 8.—TAYLOR'S MAP OF THE LAKE STAGE WHEN THE EASTERN WATERS COMBINED WITH THE WESTERN AND OUTFLOWED PAST CHICAGO.

this enlarged, it is possible that the drainage finally found its way westward into the Chicago outflow, though of this there is not yet definite proof.*

Finally the ice withdrew from the Mohawk Valley, thus opening a lower outflow than that past Chicago, and then the waters of all the lakes escaped into the Atlantic through the Hudson (Figs. 4 and 9). Before this stage was reached, the water from the western lakes found its way into the Mohawk through temporary overflow channels between the ice and the land, at levels well above the Mohawk divide near Rome. Since one of the walls of this temporary river system was the ice front, it follows that the channels were not located along the natural drainage lines of the present. Thus, temporary east-flowing streams cut channels across the hills and left various other records of their existence.† It was during this stage

* See Fairchild, papers referred to on page 225.

† See Gilbert, Bull. Geol. Soc. Amer , 1897, VIII, 285–286. Quereau, Bull. Geol. Soc. Amer., 1898, IX, 173–182.

that some of the lower delta terraces which cling to the sides of the valleys of the Finger Lakes were formed, when the water in them fell to successively lower levels, as new outlets were discovered upon the retreat of the glacier.

Just before the water began to escape by this means into the Mohawk, there existed a continuous marginal lake, broadening westward, and with an outflow through the Chicago channel. This expanded lake, made by the union of Lakes Chicago, Saginaw and Whittlesey, together with other marginal waters further east, is

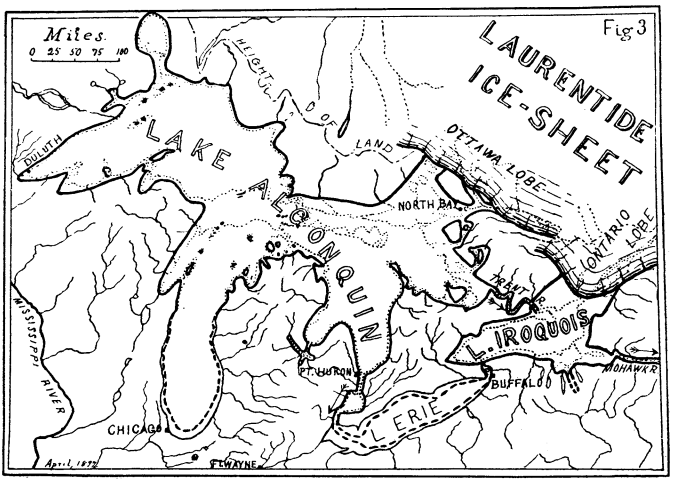

FIG. 9.—TAYLOR'S MAP SHOWING THAT STAGE IN THE LAKE HISTORY WHEN LAKE ALGONQUIN EMPTIED INTO LAKE IROQUOIS THROUGH THE TRENT RIVER (SEE ALSO FIG. 4).

known as Lake Warren. At one time it included a sheet of water parallel to the southern Erie shore, and probably also the waters that occupied the Finger Lakes region immediately after the abandonment of the Seneca divide, which had controlled the Glacial Lake Newberry. The easternmost extension of Lake Warren is not definitely known, and this connection with the Finger Lakes is merely a probability, based upon a knowledge of the fact that the waters of Lake Warren *did* extend eastward until they finally found an outflow through the Mohawk.

With the uncovering of the Mohawk, the Lake Warren waters flowed eastward, and the level fell, until, finally, the entire Erie basin was uncovered. Niagara River then began to flow when the water level in the Ontario basin fell below that of Lake Erie. The outflow of the upper Great Lakes was then, as now, through the Detroit–Lake St. Clair channel into Lake Erie; and the Niagara River was then, as

now, a large river. The three upper lakes were at that time united to form Lake Algonquin; but, as the ice front withdrew still further, it uncovered the Trent River valley, which, because of the northward depression of the land at that time, was then lower than the Detroit channel, so that the waters of Lake Algonquin were then withdrawn from the Lake Erie overflow, and the size of Niagara was greatly reduced thereby. The waters from the upper Great Lakes then flowed directly into the expanded Ontario without first passing through Erie. The expanded Ontario has been called Glacial Lake Iroquois (Figs. 3 and 9), and its overflow was through the Mohawk, because the St. Lawrence outflow was still ice-filled.

It will be noticed on the map (Fig. 9) that the shore lines of Lake Algonquin, in the Michigan region, disappear below the lake waters north of Chicago, and also that the outflow of the upper Great Lakes is marked as being through the Trent River, although we know that this is now higher than the Detroit outlet, which was abandoned in favor of the Trent. The proof of this change is found in the convergence of the beaches toward the Trent River and the evidence that a large river formerly occupied it. The tilting of the beaches is in harmony with all the other evidence, and it seems that an uplift of the land was in progress during the time of the retreat of the ice.

All the beaches of the lakes are somewhat tilted, although the oldest are most affected. This tilting, which on the Iroquois beaches of New York is about five feet per mile in a northeasterly direction, has elevated many beaches high above the level of the present lakes. One passes upgrade in going along these shore-line deposits in a northeasterly direction. That this uplift was in progress while the lakes existed is shown by the difference in inclination of the older and younger shore lines.

The uplift seems also to have shifted the outflow of Lake Algonquin once more to the Detroit Channel, thus causing the Trent River to be abandoned and Niagara River to become enlarged once more.

Finally the ice withdrew from the St. Lawrence valley, so that the level of Lake Iroquois fell, but not to the present level of the Thousand Island outflow, for the valleys of the St. Lawrence, Hudson, Lake Champlain, Ottawa, and probably also Lake Ontario, were then occupied by the sea, because of the northeasterly depression of the land. The proof of this depression comes from the discovery of marine beaches with marine fossils in the St. Lawrence, Ottawa and Champlain Valleys. While there is no direct

proof, there is some evidence in favor of extending the area of the sea beyond that indicated by Taylor, so as to admit the salt water into the Lake Superior basin.*

By the withdrawal of the glacier, the valley now occupied by the Nipissing Lake and the Mattawa and Ottawa Rivers was uncovered; and, in the depressed condition of the northern land, this was so much lower than the Detroit Channel that the volume of Niagara was again reduced to that of a small stream draining only the Lake Erie basin (Figs. 5 and 10). Taylor believes that this period, when the Nipissing Great Lakes were coalesced and had an outflow through the Ottawa into the St. Lawrence sea, was a very long one, for he finds that the Nipissing shore lines are the most

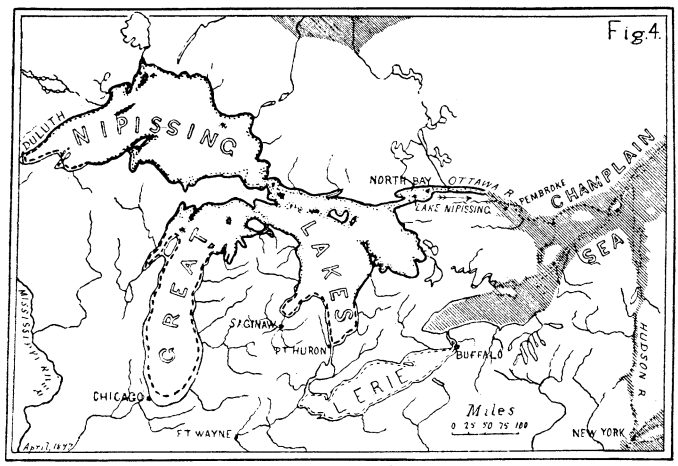

FIG. 10.—TAYLOR'S MAP OF THE GREAT LAKES DURING THE ENCROACHMENT OF THE OCEAN WATERS INTO THEIR BASIN.

strongly developed of the elevated beaches. During this stage Ontario was occupied by an arm of the sea, Erie by a small lake in its eastern end, because of the tilting of the basin toward the northeast, and the three upper lakes by a single lake, united by the same channels as at present, only slightly larger and deeper, as were the lakes themselves in the northern part. Because of the depression of the land, the southeastern ends of the Nipissing Lakes were lower than the present lake surfaces, and the northern and eastern portions higher. These points, as well as the others mentioned, have been more or less well established by the careful and detailed study of the beaches, mainly carried on by Taylor, as described in the articles referred to above (p. 221).

* See references, p. 227.

The land continued to rise, lifting the Ontario basin above the sea, and establishing the Thousand Island overflow. At first, owing to the depressed condition of the land in the eastern portion, Lake Ontario did not reach as far westward as now, and the Niagara River flowed for several miles over land now covered by the lake water. The proof of this is found in the existence of a submerged continuation of the Niagara River channel over the lake bottom, and a delta off the mouth of the present river. For the same reason, as has been stated, Lake Erie was smaller than now, and confined to the eastern end; but, as the land was elevated, the lakes assumed more and more nearly their present form, and during the progress of this uplift, the outflow was once more shifted to the Detroit channel, because the Nipissing outflow was elevated higher than the present outflow of the upper lakes. This channel has since then been continually occupied, and Niagara has since then had approximately its present volume. If the uplift is still in progress, as suggested by Spencer,* and as Gilbert has attempted to demonstrate,† there may in the future be still another change in direction of the Great Lakes' outflow, this time past Chicago. The evidence of the numerous and often tremendous past changes, which is so clear, should offset skepticism concerning the possibility of still other future changes. The land is unstable, and the future has many changes in store, and perhaps the disappearance of Niagara may be one of these.

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* See references on p. 220.

† Nat. Geog. Mag., 1897, VIII, 233–247; Eighteenth Annual Report U. S. Geol. Survey, 1898, 595–647.